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FINAL REPORT

IONIC SOUND WAVES IN PLASMAS

A Research Project Supported by NASA Grant
in the Space-Related Sciences

NsG-518

Project No. DRI-615

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UNIVERSITY OF DENVER

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SUBMITTED BY:

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ABSTRACT

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Apparatus for the study of collision-dominated pressure waves in a plasma has been designed. The plasma is a direct-current glow discharge in ultrapure helium. Acoustic pulses are generated by a diaphragm and detected by an electron-mobility type microphone.

Author

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I. INTRODUCTION

The propagation of pressure disturbances in an ionized medium is of considerable geophysical interest. At altitudes between 50 km. and 100 km., corresponding to the ionospheric D-layer, the daytime atmosphere is a very weak plasma with a fraction ionized that may approach 10^{-10} at the upper boundary. The pressure range in this region is from about 1 mm. Hg down to 10^{-4} mm. Hg while the mean free path increases from 10^{-3} cm to 20 cm. This region corresponds to the upper altitude limit for ordinary acoustic propagation.

Between 100 km. and 150 km., which is the lower E-region of the ionosphere, the fraction ionized rises to about 10^{-5} while the mean free path increases to about 45 m. Only low-frequency acoustic waves can propagate under these conditions without practically complete absorption. At still greater altitudes the fraction ionized continues to increase as collisions between the molecules become less frequent.

With respect to pressure-disturbance propagation, therefore, the atmosphere presents a continuous gradation of conditions from those in which molecular collisions are dominant and ordinary acoustic propagation predominates to those in which collisionless ion waves predominate. The transition region in which both collisions and ion-wave propagation are important is naturally of great interest.

Collisionless ion-waves have been studied by Wong, Motley, and d'Angelo[1] in a cesium plasma, and by Alexeff and Jones[2] in noble-gas plasmas. The velocity V of these waves is given by the formula

$$V = (\gamma k T_r)^{\frac{1}{2}} m_i^{-\frac{1}{2}}$$

where k is Boltzmann's constant, T_e is the electron temperature, m_i is the ion mass, and γ the compression coefficient. Alexeff and Jones found that $\gamma \simeq 1$ under the conditions of their experiments, which correspond to isothermal waves.

For collision-dominated waves, the velocity is

$$V = (\gamma k T_i)^{\frac{1}{2}} m_i^{-\frac{1}{2}}$$

where, in a monatomic gas $\gamma = 5/3$ and T_i is the ion and neutral temperature. The ion waves and the normal acoustic waves are coupled by ion-neutral collisions. One expects that in the intermediate range there will be two strongly-interacting propagation modes.

We therefore were interested in the development of apparatus to study the propagation of pressure pulses in the transition region between the collisionless and collision-dominated processes, with particular interest in the behavior of normal acoustic waves. The experimental apparatus was designed to allow the propagation of acoustic pulses through the plasma medium and consists of a discharge tube with an acoustic source and receiver mounted in side-arms. The discharge tube and acoustic tube were built and tested separately. These tubes were to be combined after each operated successfully by itself. The project terminated for lack of funds before this was done, but not before the feasibility of the design of the separate components was established. Proposals for further support have been made.

The next section will discuss the apparatus as constructed.

II. EXPERIMENTAL APPARATUS

The discharge tube and associated equipment will be described first, followed by a description of the acoustic apparatus.

1. Discharge Tube

The plasma medium is provided by a direct current glow discharge in ultra-pure helium. This discharge is identical to that described by Persson,[3] called by him a "brush cathode plasma" except that our cathode is a plain, flat stainless steel plate. The fraction ionized is about 10^{-1}, and the electron temperature is in the range 1000-1800°C. The discharge tube is illustrated in Figure 1. Details of the vacuum system are given in Figure 2.

The helium is introduced through a home-built quartz leak. A section of thin wall quartz tube is wound with resistance wire and sealed into the system. An outside pyrex tube provides a means to surround the quartz tube with an atmosphere of commercial helium at atmospheric pressure. Upon heating, the quartz becomes permeable only to helium.

The vacuum pump is a three-stage glass diffusion pump (CVC Model GF-25) with polyphenyl ether ("Convalex-10") working fluid. The pump is trapped only with a glass sorbent filter. All the vacuum system except the pump and the discharge tube itself are contained in a bakeout oven. This system reaches a pressure below 10^{-8}mm. after approximately 12 hours of bakeout at 450°C, which proved sufficient to insure a suitable discharge. A portable bakeout hood is used over the discharge tube for part of the bakeout time.

The power supply is a Harrison Labs Model 6522A, rated at 0-2000 volts and 0-100 ma, connected directly across the discharge tube. The discharge has a positive current-voltage characteristic that allows this type of connection. Should an arc appear, the power supply is also current-limiting and no difficulty is experienced.

When first built, the glassblower allowed a sharp point to remain when connecting the anode wire to the wire through the anode lead seal. This limited the voltage that could be applied to the tube by causing an arc from cathode to envelope, along the surface of the envelope, and finally from the envelope to the sharp point. This

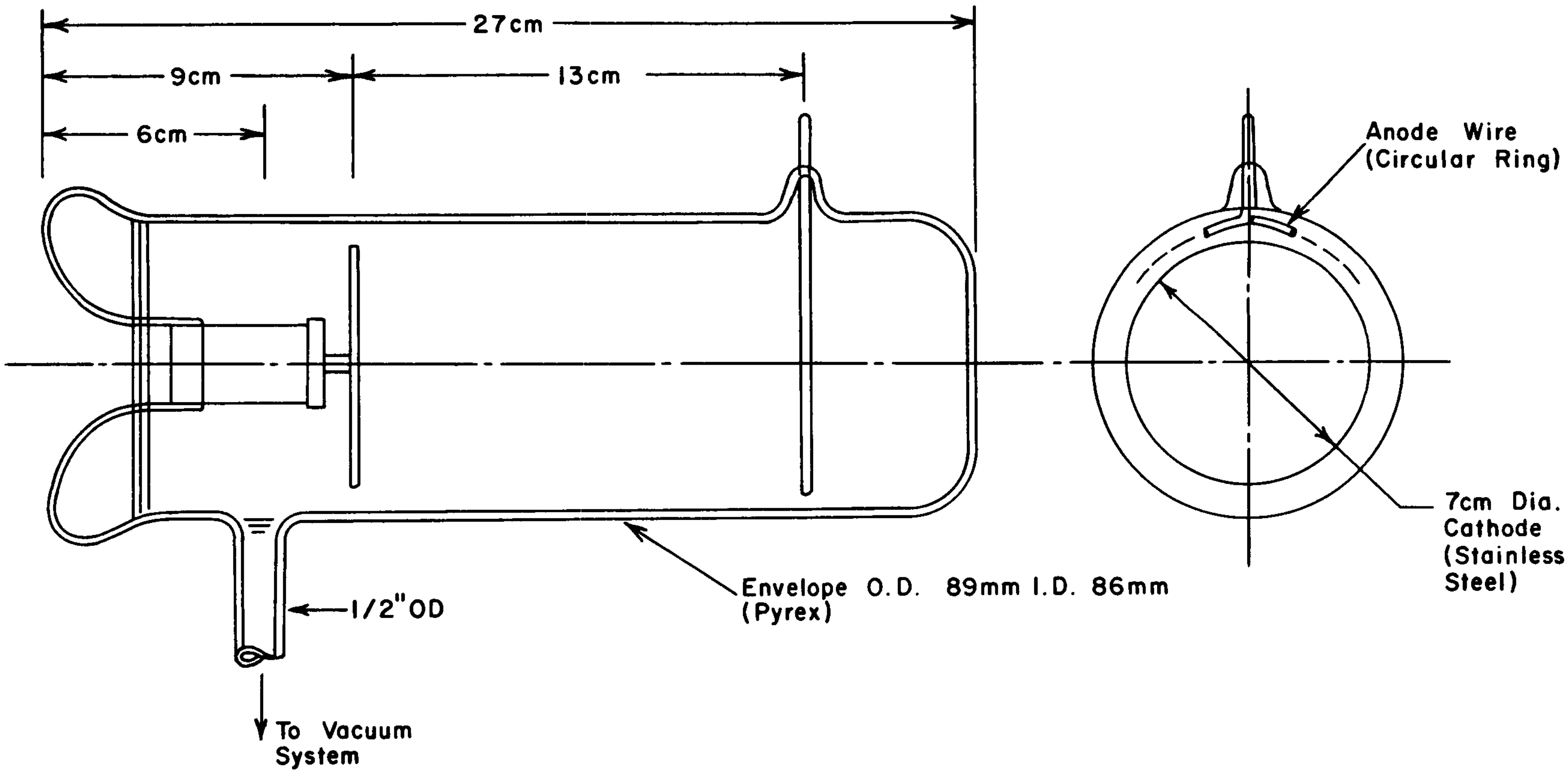


Figure 1. Discharge Tube

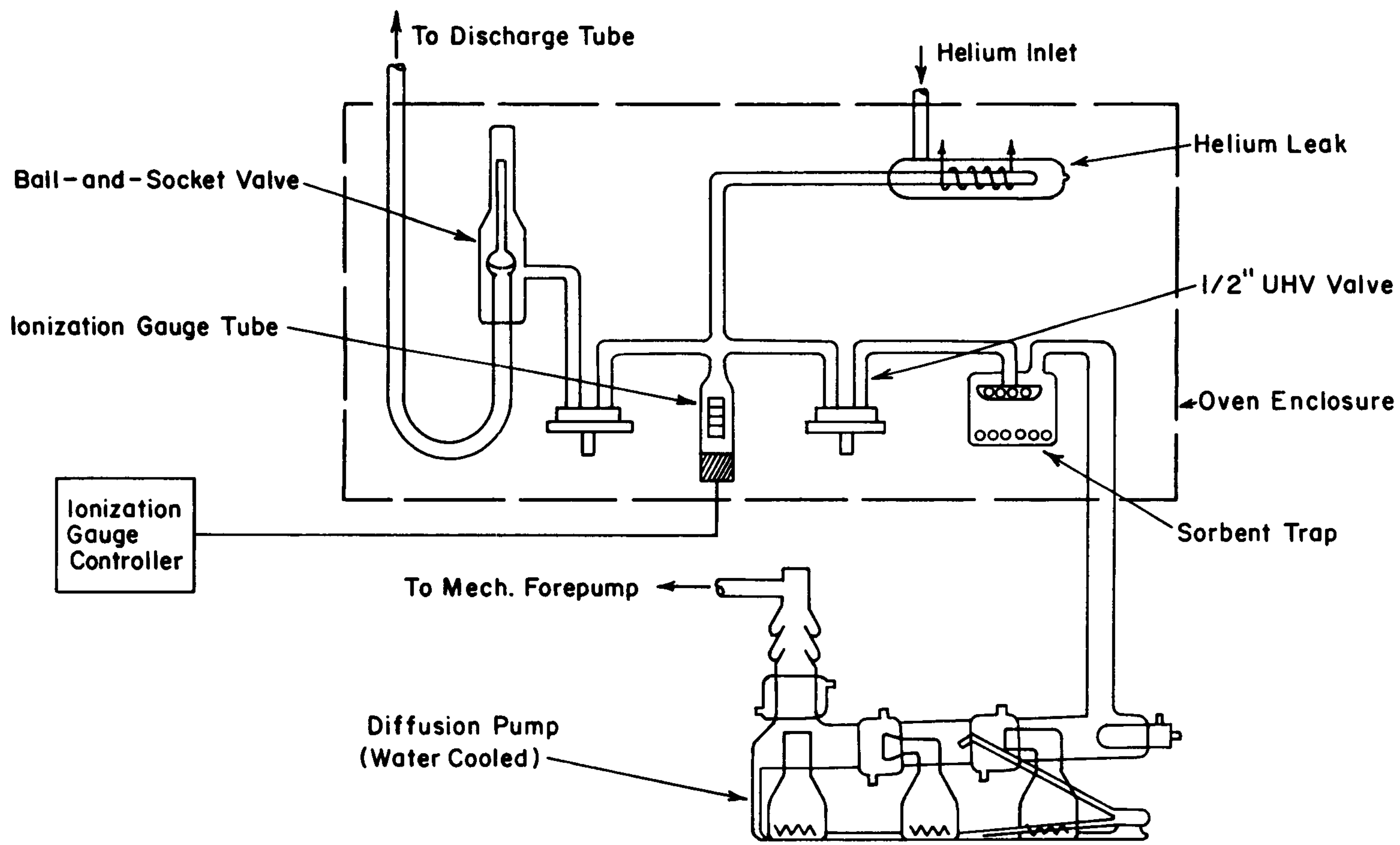


Figure 2. Vacuum System

difficulty is easily corrected by eliminating the sharp point and cleaning the envelope.

In operation, the discharge is very stable. Beyond the bluish cathode glow, which appears as a thin region parallel to the cathode and about 1 cm. in front of it, the tube is filled with the characteristic pink glow. With normal illumination, the discharge first appears at a potential of about 650 volts when the pressure is about 0.1 mm. (current less than 5 ma).

2. Acoustic Apparatus

The acoustic apparatus that was constructed is shown in Figure 3, and a block diagram of its connections appears in Figure 4. This form of the apparatus was relatively unsatisfactory on two counts. First, the steel diaphragm could be attached only with soft solder because the shim steel stock could not be heated above its annealing temperature without wrinkling. This property would interfere with the proper bakeout necessary to insure purity in the discharge. Second, the receiver was very sensitive to noise and required considerable shielding to increase the signal-to-noise ratio to an acceptable level. Part of this difficulty was due to an insufficiently intense signal from the diaphragm.

The microphone consists of a type 15E triode with the grid removed. The resulting diode is operated at a plate voltage below the ionization potential of the gas. The plate current is controlled by the electron mobility in the gas between filament and anode, which, because it is pressure-dependent, allows the detection of pressure pulses. This device is described by Dayton, Verdeyen, and Virobik.[4]

The operation of the acoustic apparatus to determine time delay between emission and detection of the pulse is straightforward. The pulse generator drives the diaphragm by means of an earphone electromagnet, at the same time triggering the oscilloscope sweep. Variations in the plate current of the microphone diode are amplified and displayed on the oscilloscope. The time delay is measured by the calibrated sweep of the oscilloscope.

The speeds measured cannot be interpreted as free-space values unless the rise-time of the pulse is shorter than about 0.01 msec, considering the diameter of the acoustic tube and the speed of sound (about 920 msec at 22°C). The travel time of the leading edge of the pulse in

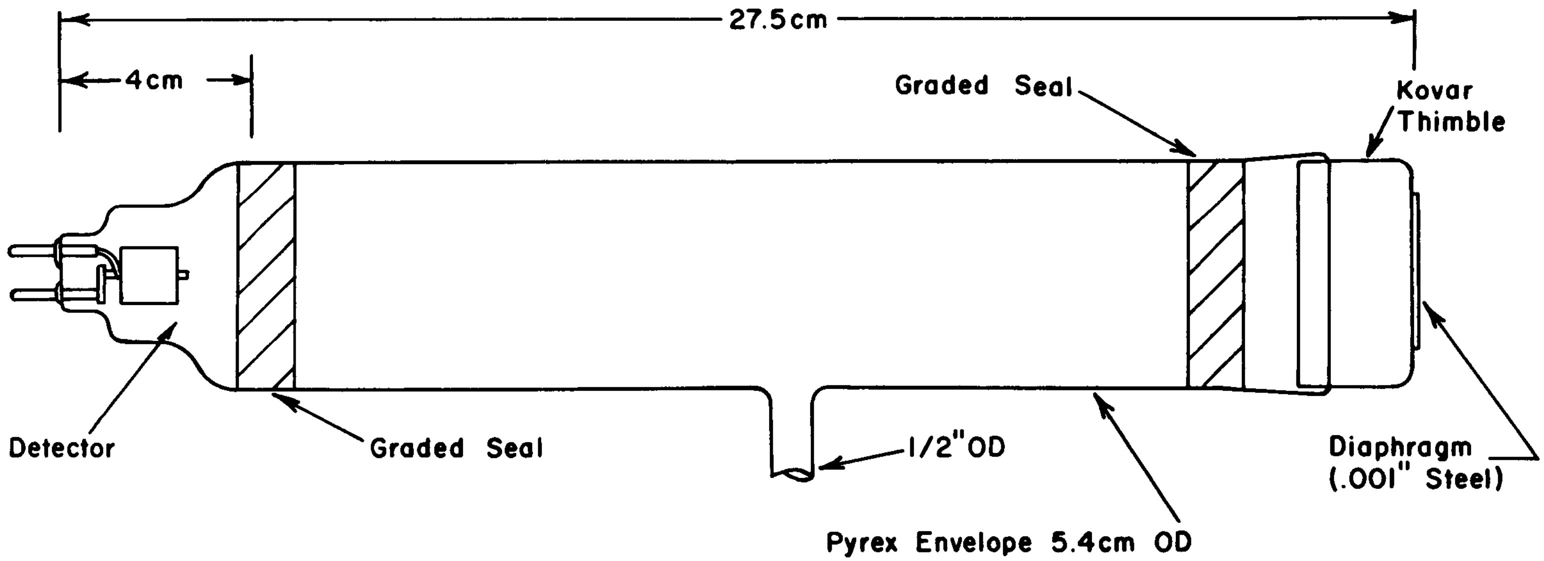
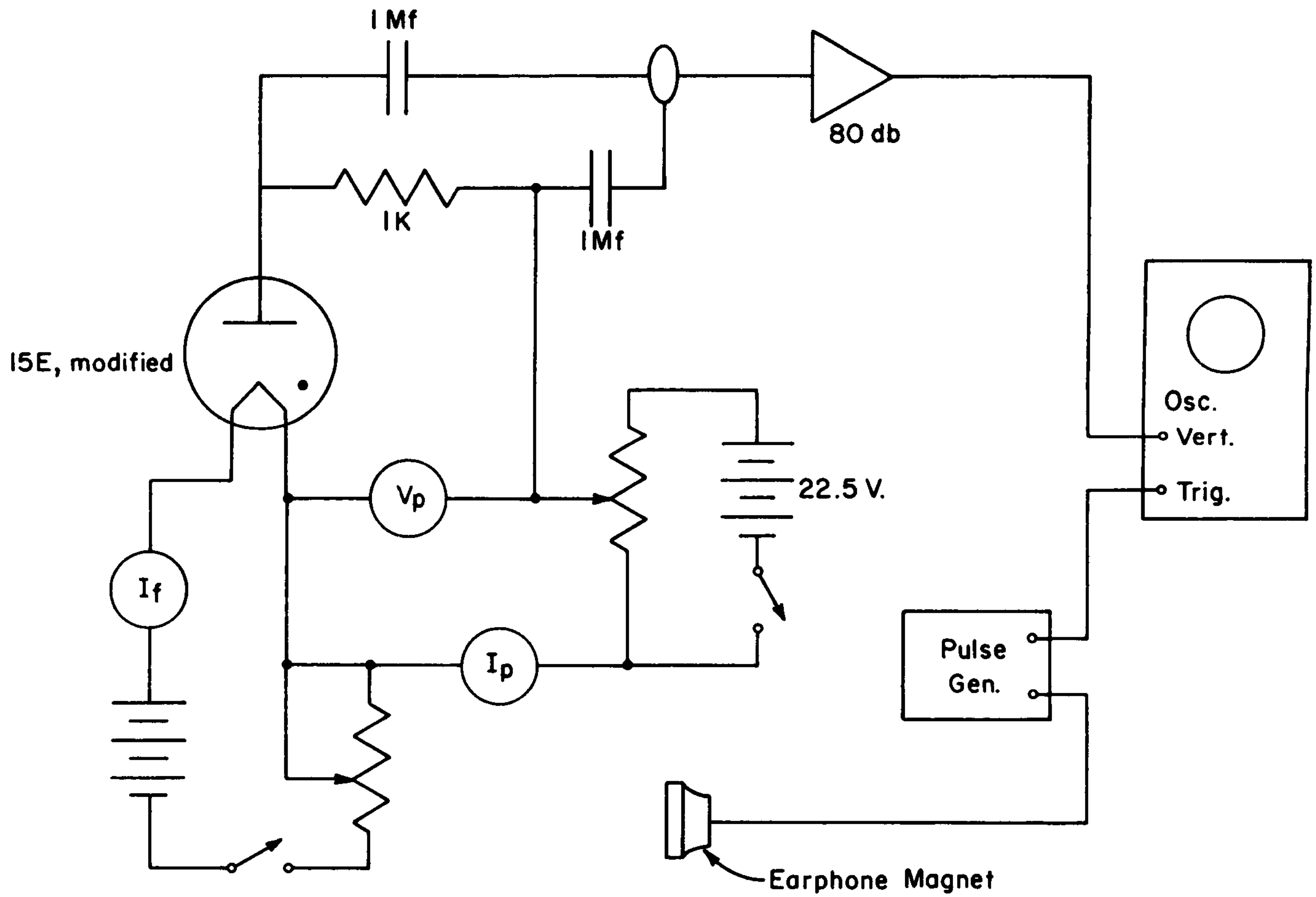


Figure 3. Acoustic Tube



Amplifier: Two Hewlett-Packard 450A
Pulse Generator: Gen. Radio 1217C
Oscilloscope: Tectronix 535-S6

Figure 4. Detector and Source Circuitry

helium is about 0.25 msec. The measurements were made at a pulse repetition rate of 1 kc/sec with a pulse of 0.1 msec duration. Acceptable values of the sound speed were determined in argon and helium, to an accuracy of about 10%. The error was due chiefly to noise masking the beginning of the pulse. Reflected pulses could not be seen because of the high attenuation. The pressures used were in the vicinity of 1 mm. of mercury.

III. DISCUSSION

The most difficult problem in the development of this type of apparatus is the design of the acoustic apparatus. As we have seen, the diaphragm that was used was not only of unsatisfactory construction (soft solder necessary) but yielded a rather low pulse intensity. To correct the constructional difficulty, it would be necessary to turn the diaphragm on a lathe from a material that could either be sealed into glass or silver-soldered to Kovar. Kovar itself does not machine well enough to obtain a thin diaphragm. From practical considerations, it would seem difficult to turn a diaphragm as thin as the one in use (0.002"), and therefore the driving force must be increased. A possible answer could be a non-magnetic diaphragm driven by a ferrite core and electromagnet.

Two methods are available to avoid the diaphragm in the wall of the tube: a piezoelectric source or a ribbon-type speaker. The peizoelectric source requires a high voltage for operation and is hence unsuitable due to breakdown. The ribbon-type speaker is a possible choice, but mounting it in the tube so that it will be compatible with the ultrahigh vacuum must be considered. A speaker inside the tube must also be baffled to eliminate back-radiation. Speakers inside the tube seem to have no advantages over the wall diaphragm.

The microphone that was used seems to be the most satisfactory available. At the low pressures used in the experiments, no material diaphragm could couple well enough with the medium. One important factor could not be investigated: the effect on the signal of the electrodes drawing plasma current when operated in conjunction with the discharge. It is possible that the pressure effect would be masked by the changes in current drawn from the plasma, and a simple probe would yield the same information. There is a possibility of isolating the microphone sufficiently to reduce greatly the plasma current drawn (for example, by a glass-wool plug).

Proposals for further support of this work have been issued.

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